NOVEL HYBRID PHOTOVOLTAIC AND THERMOELECTRIC PANEL

By

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Dissertation submitted in partial fulfillment of
the requirements for the
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CERTIFICATION OF APPROVAL

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TRONOH, PERAK

SEPTEMBER 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MOHD MUNZIR BIN MOHD DAUD

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ABSTRACT

Nowadays, hybrid system from alternative energy has been developing drastically in order to fulfil the demand on electricity. One of that energy is solar energy that produces radiant light and heat that can be converted into electricity. Photovoltaic (PV) cell can be used to react with radiation and emit electrons resulting in electric current because of the flowing of electron charge over time. Then, thermoelectric module that use thermocouple (TE) concept can generate electricity because of the different temperatures between two layers of semiconductor material. PV cell and TE module will be integrated together to increase efficiency of electricity generation. The efficiency depends on solar radiation and solar heat temperature. Then, the liquid cooling system integrated together with prototype panel to maintain lower temperature at cold junction of TE module. So, the bigger difference of temperature between TE module junctions will produce more voltage and more electricity. This innovation has no emission and requires less maintenance. So, it can be considered as one of the green technologies for hybrid system.

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LIST OF ABREVIATIONS

PV	Photovoltaic
TEG	Thermoelectric Generator
TE	Thermoelectric
TEM	Thermoelectric module
LED	Light-Emitting Diode
V	Volt
A	Ampere
W	Watt
dBA	Decibel
MOSFET	Metal–Oxide–Semiconductor Field-Effect Transistor
DC	Direct Current
$\mathbf{Bi_2Te_3}$	Bismuth Telluride
PESC	passivity emitter solar cell
SiH_4	Silane
EVA	Ethyl Vinyl Acetate
PbSe	Lead Selenide
SiGe	Silicon- Germanium
SW	Science Workshop

CHAPTER 1
INTRODUCTION

1.1 Background of study

Surging oil prices and increasing environmental awareness lead to the growth of renewable energy in this country. Since Malaysia is situated in the equatorial region with an average radiation of 4000-8000 Wh/m^2, the potential for solar power generation is very high. [1] However, the real harvesting of solar energy is still below its actual potential. The fact show current production of PV system all over the world is about 150-200MW per year while in Malaysia is just about 5 MW per year [2]. So, the Malaysia Government encourages the development of the clean and green technologies such as solar energy as alternative power supply in order to optimize the actual potential.

Solar energy actually produce radiant light that can be harvested using photovoltaic (PV) panel and heat by using thermoelectric material. PV panel consist of the collection of individual cells made by semiconductor material that generate electricity from sunlight. The photons or particles of the light produce an electrical current as they strike the surface of silicon wafer on PV cells. PV cells generate free power from the sun by converting sunlight to electricity. This is hybrid technology which has no moving parts, zero emissions, and required less maintenance.

Apart from the radiation light, heat also produced by the sun and it will be wasted if not be utilized. By using thermoelectric module, the heat energy from the sun can be converted into electricity. Thermoelectric (TE) module has two junctions between two different semiconductors material that will produce the voltage. The voltage produced depends on temperature difference between two junctions. The bigger temperature difference, the higher voltage can be generated.

This project will integrate the PV cells and TE module that is Seebeck unit to improve the efficiency of the electricity generation. In order to maximize the voltage generated in Seebeck unit, the liquid cooling system will be attached to provide more different of the temperature.

1.2 Problem statement

The usage of oil and other non-renewable resource to generate electricity gives huge contribution to the green house effect and lead to global warming. There is also a problem with a decreasing resource of oil that causes the rising of the oil price drastically. The demand for electricity keeps increasing from all over the world. Thus, it needs to develop renewable energy source as solution. There is in fact plenty of available energy but it is not been used due to lack of technology. One of the available energy is solar energy that is an environmentally friendly alternative to produce electricity.

The PV system is the common technology used to absorb solar radiation from the sun and convert it into electricity. However, the PV cells produce low efficiency that is between 4% until 18% depends on type of cells used. Then, PV cells efficiency will decrease as the temperature of PV cell increase. So, this project will develop hybrid energy by utilizing both radiant light and heat of sun by using PV and TE technology. Then, the liquid cooling system is used for the prototype panel to maintain the lower temperature of TE module. The innovation of this project is to improve the efficiency of this traditional PV panel.

1.3 Objectives

The goal of the is study to develop a prototype of hybrid photovoltaic and thermoelectric solar panel utilizing radiation and heat as it main source of electricity generation. It has the following specific objectives:

a) Feasibility study of photovoltaic (PV) and thermoelectric (TE) technology.
b) Develop a prototype of hybrid photovoltaic (PV) and thermoelectric (TE) panel.
c) Testing the efficiency of the prototype panel in comparison to traditional PV module.

1.4 Scope of study

The scope of study consists of three major parts which are:

a) Research the development of solar energy harvesting today and potential to improve the system available. The finding will give some ideas and relevant solutions to develop and improve new system of solar energy system.
b) Identify the method and technique that suitable to develop new hybrid solar energy system that harvest from both thermal and radiation.
c) The experimental work is data gathering and identifying the processes and disturbance model of the application.

1.5 Feasibility of the project prototype

This project was completed within 6 months which begin with the study of current PV and TE technology from previous research. After that, the main materials of PV cells, TE module and liquid cooling system are selected and were purchased. This study and selecting the materials was completed in FYP 1. Then, this project was continued with design and fabricates the prototype panel during FYP 2. After the fabrication of prototype panel was completed, the efficiency test of prototype panel was conducted and the result was verified.

CHAPTER 2
LITERATURE REVIEW

2.1 Solar energy

Basically, solar energy comes from the sun that emits two type of energy that is radiation and heat. Radiation and heat from solar energy can be used to generate electricity from photovoltaic and thermoelectric effect [3]. PV cell is used to capture the radiation. PV cell is sensitive to different wavelength of the light. So, different type of semiconductor material is used to build solar cell depending on its function. Then, the other technology that can used to capture energy from the sun is thermoelectric module. Thermoelectric module can generate electricity from the heat of the sun.

2.2 Photovoltaic (PV) system

2.2.1 Working principle of PV system

Photovoltaic (PV) cells generate electricity when exposed to sunlight. Silicon is main material for photovoltaic cell and impurities such as boron or phosphorus are added to this base material to create the environment for electrons to be freed when sunlight hits the photovoltaic panel [4].Photovoltaic effect causes solar cell to absorb photons of light and release electrons and then free electrons flow resulting electric current [5]. PV system not only depends on the conversion efficiency of the semiconducting silicon, but also is closely related to the transmittance of light through cover glass [6].

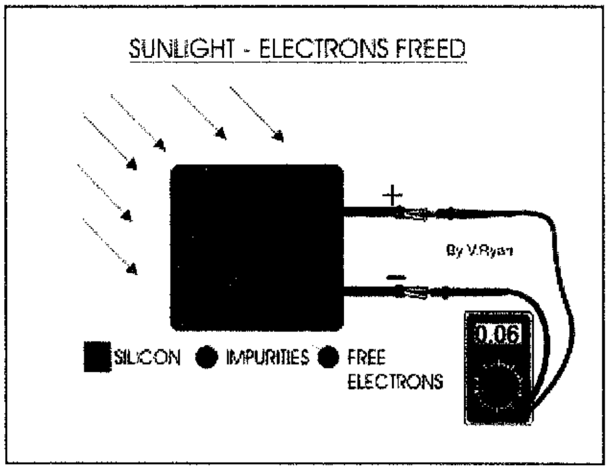


Figure 2.1: The diagram for typical photovoltaic cell [4]

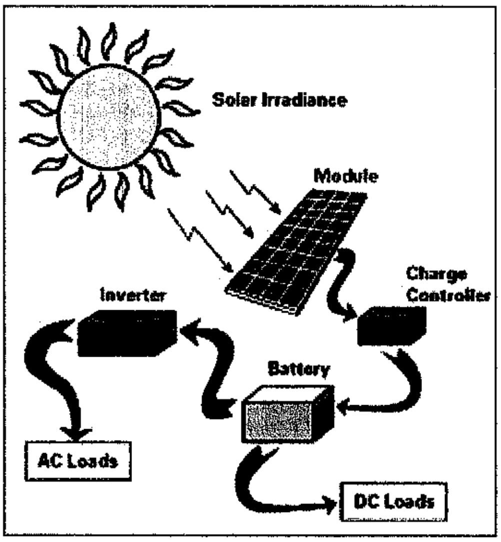


Figure 2.2: The diagram of typical PV system [7]

2.2.2 *Type of PV cell*

There are several types of solar cell commonly use in solar industry today. The most sensitive solar cell to the radiation is monocrystalline silicon. Monocrystalline silicon cell reacts with radiation and produces electron. Then, tab wire which can conduct current collect the electron from cell and convert in to electricity current. Monocrystalline silicon is typically 12-18% efficient which means for every unit of solar energy that hits the cell; the panel can convert 12-18% of this energy into electricity [8]. This cell is most expensive than the others but they are highly efficient and are often more cost-effective in the long term.

Polycrystalline silicon solar cell made with polycrystalline cells are a little less expensive and slightly less efficient than monocrystalline cells because the cells are not grown in single crystals but in a large block of many crystals [9]. The efficiency of the polycrystalline is up to 12% [10]. By incorporating phosphorus pre-treatment and rear aluminium treatments into the passivity emitter solar cell (PESC) sequence its efficiency will improve to 17.8% [11].

Amorphous cells are made by depositing silicon onto a glass substrate from a reactive gas such as Silane (SiH_4). This type of solar cell can be applied as a thin film to low cost substrates such as glass or plastic [12]. Amorphous cell consist of 2 layer structure that is amorphous semiconductor layer and micro crystalline conductor layer where both type have the same conductivity type [13]. The efficiency of amorphous solar cells is typically between 4% and 8% [14]. The Lifetime of amorphous cells is shorter than the lifetime of crystalline cells. The ideal light source for amorphous solar cells is fluorescent lamp.

2.2.3 Construction of PV module

The essential parts of a photovoltaic generator are the cells, where the physical process converts light into electricity. Special materials are used for the construction of photovoltaic cells that is semiconductors. Semiconductor material for the construction of photovoltaic cells is monocrystalline, multi-crystalline and amorphous that are from silicon form and other materials such copper indium diselenide, cadmium telluride and gallium arsenide [15].

Most commercial modules consist of 36 or 72 cells because one PV cell can produce 0.5 to 0.6V. So, more cells connected in series will produce higher voltage. Then, PV cells are mounted on a backing material such as Tedlar (a white rubberlike product), glass or some other material which will seal and protect the cells from the environment [16]. Usually, solar cells are placed between a rear layers on the bottom and encapsulate and top surface on the top. Other than PV cell, there several important materials that needed to construct the PV module [17]:

1. Top Surface:

   The top surface usually glass or transparent plastic that allows light to enter the cell while protecting the delicate cells from damage. The top surface often has an antireflective coating as well, to increase the fraction of light transmitted.

2. Encapsulant:

   The encapsulant protects the cells, and holds together the top surface, PV cells and rear surface. Ethyl vinyl acetate (EVA) is the most common encapsulant used in flat plate modules.

3. Rear Layer:

   The rear layer protects the back surface of the module, and prevents water and gases from entering the module. Tedlar (a thin polymer sheet) is a common material for the rear layer.

4. Conduction strip:

Conductors carry electrons out of the cells, connecting the cells in the module in series or parallel, and carry electricity out of the module.

5. Frame:

The frame adds structure to the module, and can attach to the mounting structure.

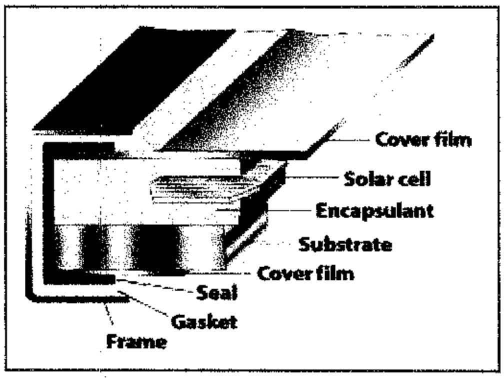


Figure 2.3: Illustration of PV module construction [17]

2.3 Thermoelectric system

2.3.1 Working principle of thermoelectric module (TE)

Solar energy can produce heat for direct use or further conversion to electricity [18]. Solar energy also produces radiation to generate high temperatures which can be converted to electricity using thermoelectric technology. This requires TE module and devices which is more efficient and low cost than available today. The electrons flow from hot to cold junctions of TE module, driven by the temperature difference will produce voltage [19]. The strength of the effect is measured by the thermo power, the ratio of the voltage produced to the applied temperature difference [20].

2.3.2 Seebeck unit

TE module can be divide into two types that is Peltier and Seebeck unit. Peltier is used for cooling purpose and Seebeck is for generating electricity. Seebeck unit consists of pairs of p-type and n-type semiconductor materials forming a thermocouple to generate electricity [21].Thermocouples that have in Seebeck unit are junction between two different semiconductors that produces voltage based on temperature difference. The area of semiconductor closed to the heat surface will produce more free charges at hot side. If there are a lot of charge, the rest of electrons in the semiconductor will be repelling each other with the result is that they tend to migrate towards the cold side [22]. The temperature different take place a transverse to thermoelectric devoted as voltage [23][24]. If we have a complete circuit, electricity will flow continuously.The bigger temperature difference; the higher voltage can be generated. This can be calculated using equation [25]:

$$V = \int_{T_1}^{T_2} (S_B(T) - S_A(T))dT \qquad (2.1)$$

S_A and S_B are the Seebeck coefficients and T_1 and T_2 are the temperatures of the two junctions. The Seebeck coefficients are non-linear as a function of temperature, and depend on the conductors' absolute temperature, material, and molecular structure. Then, the efficiency of a thermoelectric generator is can define as [26]:

$$\eta = \frac{T_H - T_C}{T_H} \cdot \frac{\sqrt{1+ZT}-1}{\sqrt{1+ZT}+T_c/T_H} \quad ; \quad ZT = \frac{S^2\sigma}{K} \qquad (2.2)$$

Here, Seebeck coefficient (S), electrical resistivity (σ), thermal conductivity (K), hot side temperature (T_H) and cold side temperature (T_C) are temperature (T) dependent materials properties. The lower value of thermal conductivity and higher value of seebeck coeeficient is better for higher value of ZT which is merit value for thermoelectric device. The higher value of ZT will contribute for higher efficiency of thermoelectric device.

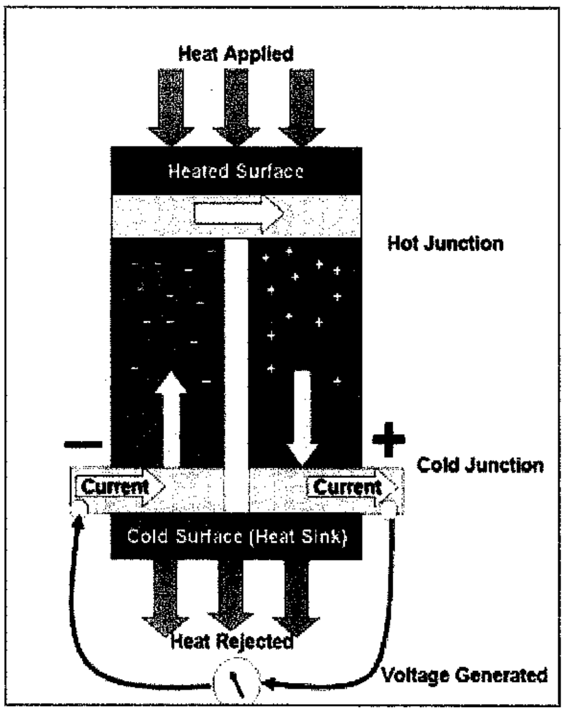


Figure 2.4: Seebeck effect [22]

2.4 Solar Thermal

Generally, solar thermal is the application of generating heat from solar energy. Solar thermal systems use reflectors or mirrors to concentrate sunlight to extremely intense levels of heat to heat up the water. The hot water will flow from thermal tank to coolant reservoir. Then, cooling pump will pump the cool water to the output heat exchanger. The flowing of heat from hot to cold side will produce the difference of temperature thermoelectric assembly and will generate electricity [27]. The figure below is the example of module use for solar thermal system.

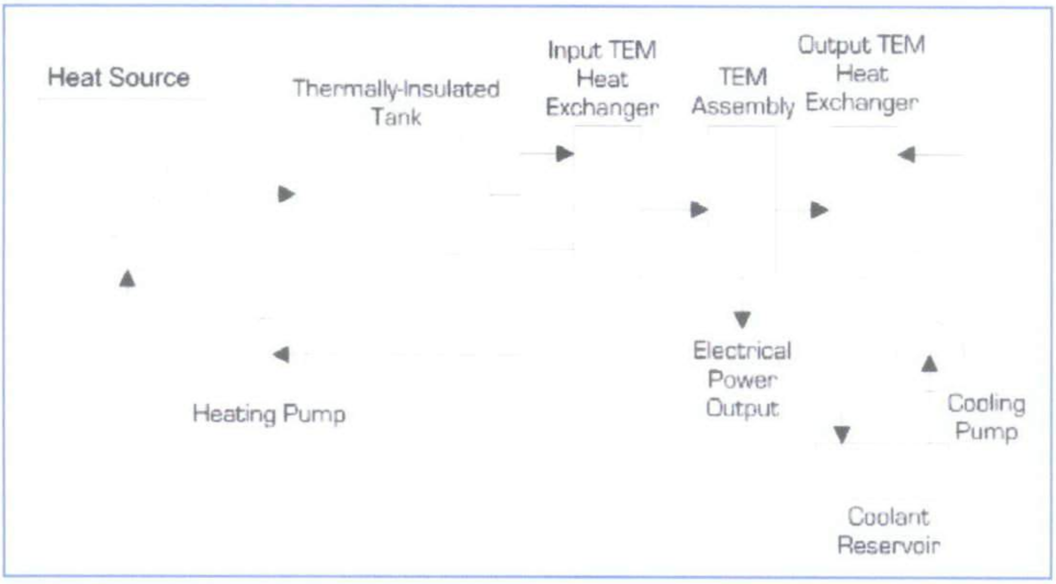


Figure 2.5: Diagram of thermoelectric module (TEM) [27]

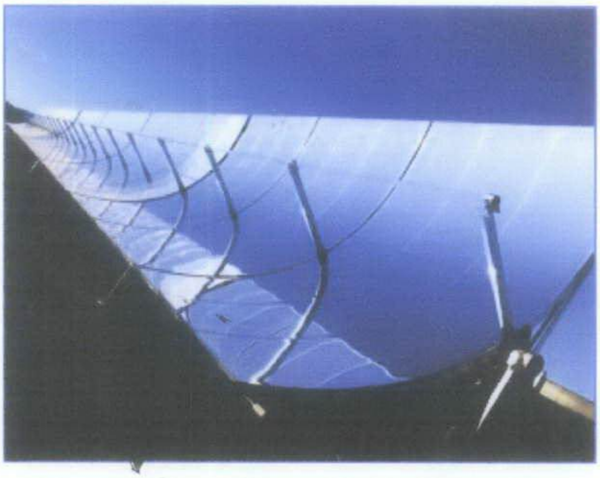


Figure 2.6: parabolic reflector of solar thermal system [28]

Solar thermal have high potential of development in power generation. But there are several drawback of solar thermal that need to be overcome. Solar thermal collector applied at domestic and commercial sector to collect the heat. Therefore, solar thermal application is limited and depends on heat demand. Then, source of heat from the sun only available during daytime and collector cannot absorb heat without source of heat energy [29]. Then, it needs big space and need high initial cost for installation and facilities. The other drawback of solar thermal is the low efficiency of generating power that is between 4% until 4.5%.

There are alternative that use to overcome the problem of solar thermal to produce electricity during winter season. One of the alternatives is using the cooling system which utilize the cold temperature from the winter [30].This alternative is better than making the bigger system of solar thermal to generate more power as back up for winter season.

CHAPTER 3
METHODOLOGY

This chapter will tell about the methodology which is used to complete this project. The section cover on justification of material used, fabrication of prototype and the test that need to be conducted to proved that this project meet the objective requirement.

3.1 Procedure identification

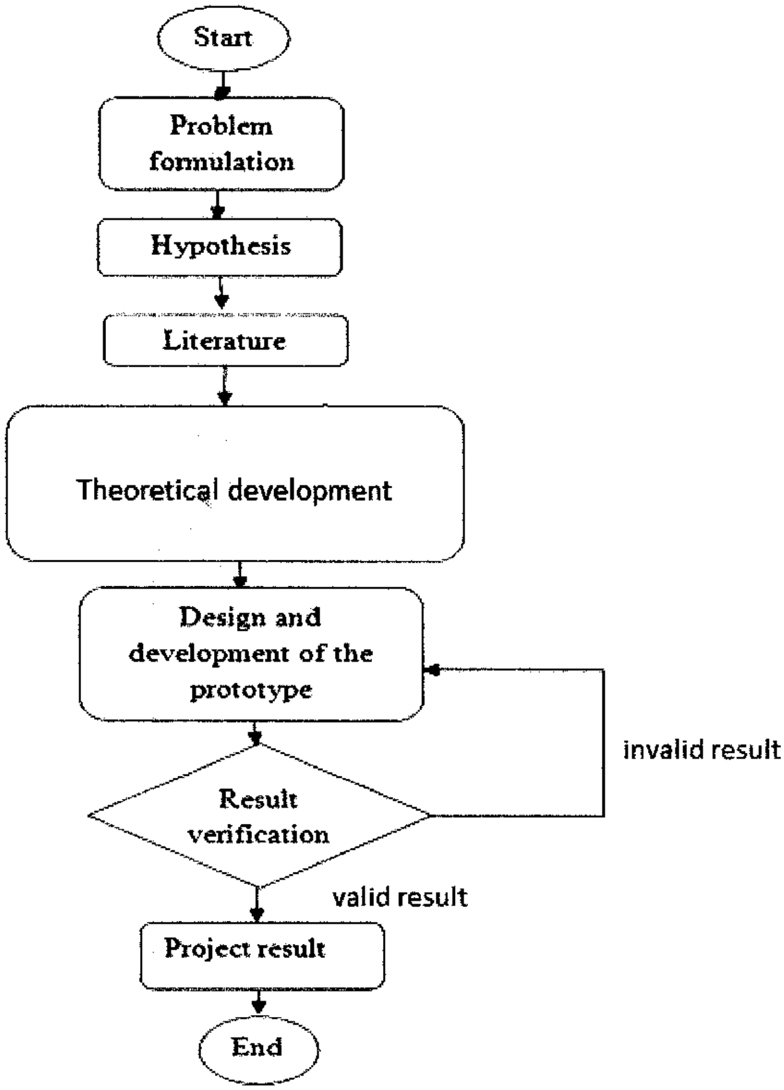


Figure 3.1: Procedure identification

The procedure identification is very important part to plan the flow of work flow. So, the project will be more organize and will get the better result. In order to achieve the objective of the project, this entire step must be followed properly. These are the description of the step identified:

i) Problem formulation:

The stand alone PV cell use today has very low efficiency in generating electricity. So, the utilization both radiant light and heat from sun energy will increase conversion of total efficiency.

ii) Hypothesis:

The integration of both PV cells and TE module utilize both radiation and heat from the sun expected to increase the efficiency of the final product of prototype.

iii) Literature and research:

The information related to the PV, TE and solar thermal technology from books, online material, and journal. This step required to understand the concept and know the current technology of PV, TE and solar thermal that already available in the market today.

iv) Theoretical development:

From the previous research source, the efficiency of polycrystalline silicon PV cells is up to 12%. Then, the efficiency of bismuth telluride type of thermoelectric module is about 4.5%. But the conversion of heat into electrical power depends on different temperature between hot and cold junction.

v) Design and development of prototype:

After understanding the concept, the best materials need to be selected. But some of the efficient material is hard to find. So, the backup materials needed to ensure this objective of this project can be achieved. Then, the modelling is done by using Solidwork 3D mechanical CAD. The importance of the design part is to ensure the transfer of heat from PV cell to the TE module can be optimized.

vi) Result verification:

After complete the fabrication of the prototype, the experimental test must be conducted to get the real result. There is several test equipment needed in this procedure. First of all radiation measurement needed to know how much radiation from solar at particular time. Then, several experiments will be conducted to find the output power from prototype panel and convert it into efficiency. Some proper equipment needed to get the continuous data from the experiment. The measurement needed for this experiment is current, voltage and temperature. Then, the modification is required to improve the performance of prototype if not meet set standard.

vii) Final result:

All the data from experiment will be gathered and analyzed. The valid result that meet the requirement by set standard and fulfil the project objective will be the final result.

3.2 Material for prototype

After doing the justification, this is the finalize material that chosen based on efficiency, cost, size, and other specification such as rated current, rated voltage and rated power. The easiness to get the material also important because the time constraint to complete the project. These are the materials choose for the project:

3.2.1 Polycrystalline silicon PV cell

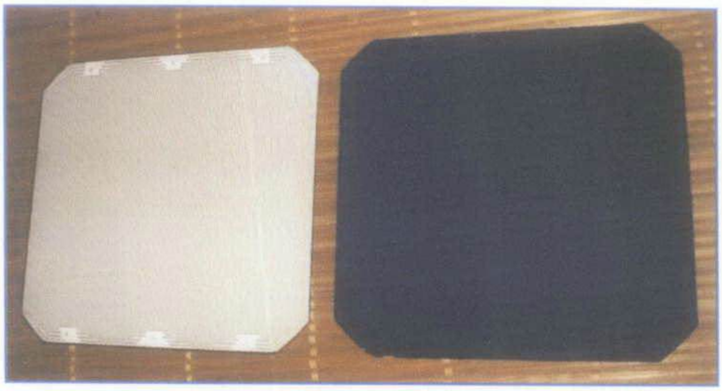


Figure 3.2: Polycrystalline Silicon PV cell

Polycrystalline silicon solar cells have photoelectric conversion efficiency of about 12%, slightly lower than the monocrystalline silicon solar cells, but the material is simple, to save power consumption, the total production costs low, so get a lot of development. The rate of this PV cells is 0.6V and 2.5A of each unit. The dimension of each PV cell is 12.5cm x 12.5cm. This PV cells can be connected in series to gain higher voltage for certain application but the load must be estimated first before sizing the PV panel for enough storage of supply to the load.

3.2.2 Thermoelectric (TE) module:

Figure 3.3: Seebeck unit TEG288-62A

Generally, there are two type of TE module that commonly used today. One of them is Peltier which is use for cooler purpose. Then, the other TE module is Seebeck unit which is used as main material in this project. Seebeck unit which is higher efficiency of electricity generation is needed. The measurement material properties of Seebeck unit is based on Seebeck coefficient (S), electrical resistivity (ρ), and thermal conductivity (K) [31]. Currently, Bismuth Telluride is the best type of the material used in Seebeck manufacturing because it is most efficient compare to other type of material for the temperature between 5°C to 70°C or 278K to 343K. Furthermore, the efficiency of Bismuth Telluride increase as temperature increase if temperature below 350 K. The Figure 3.4 show the characteristic of TE efficiency against average temperature of Bismuth Telluride (Bi_2Te_3), Lead selenide (PbSe), and silicon-germanium (SiGe):

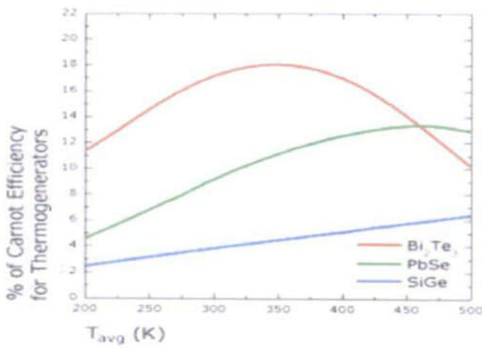


Figure 3.4: The graph of efficiency against temperature

The type of seebeck unit that we choose is Bismuth Telluride with 288 P and N junctions. The Open circuit test voltage is 15.2 Volt and short circuit test current is 10 Amp. The quantity of seebeck unit used in this project is 4 units. 4 unit of Bismuth Telluride thermocouple are arranged electrically in series and thermally in parallel to increase the voltage produced. Figure 3.3 show the photo of seebeck unit TEG288-62A and the specification as below:

P-N Couples:	288
Imax(A):	10
Vmax(V):	15.2
Dimensions(mm):	62 × 62 × 4.0
P/N Element Size (mm):	1.6 × 1.6 × 1.2

3.2.3 Aluminium plate:

Aluminium is chosen because it is a good metal for heat dispersion. More over aluminium is a low density metal that is $2.7gcm^{-3}$ and able to resist corrosion. It also durable and lightweight which means it is user friendly. Although aluminium is soft, it is ductile and malleable metal which is able to deform under tensile pressure. The thickness of the aluminium need to be moderate which is 1mm to ensure the heat transfer is fast enough to respond to the change of temperature due to the solar energy received.

3.2.4 Liquid cooling system:

Liquid cooling system consists of micro pump, radiator, liquid reservoir and copper fin. All of this equipment is integrated in one system and circulate the glycol liquid as coolant agent to the cool down TE module temperature. Glycol is the liquid used to improve heat transfer and heat dissipation.

Figure 3.5: H50 liquid cooling system

Figure 3.6: Micro pump motor

Figure 3.7: copper cooling plate

Specification:

- Cold plate material: copper
- Fan : 120mm, 170RPM, 12V, 50 mA
- Micro pump: 12V, 100mA, 10mL/ min discharge rate
- Radiator material: aluminium
- Tubing: low permeability for near-zero evaporation
- Fluid: Deionised water with propylene glycol to prevent corrosion.

The features of H50 liquid cooling system:

- H50 is closed loop system which means it easy for installation.
- Copper cooling plate for maximum cooling performance.
- Integrated pump and reservoir is sealed for zero maintenance and improved leakage protection.
- Large 120mm radiator for fast heat dispersion.
- High efficiency and low noise fan to draw cool air across radiator.
- Total weight of H50 is 700g.

3.3 Construction of PV panel

Figure 3.8: Construction of PV panel

The PV cell type that used for this project is polycrystalline cell which has efficiency of 12%. PV cells will be series connected for 12 units by using the copper wire. The dimension of 1 unit of PV cells is 12.5cm x 12.5cm give the total 0.1875 m^2 of dimension area. Each PV cell rated at 0.6V voltage and 2.5A current. So, the total voltage that can produce by 12 units of this PV cells is 7.2V and applicable to charge 5V battery for the storage. Then, the power rated for this PV panel is 15W. The other materials used are glass and multilayer back sheet for PV cells protection.

3.4 Construction of TE module with liquid cooling system

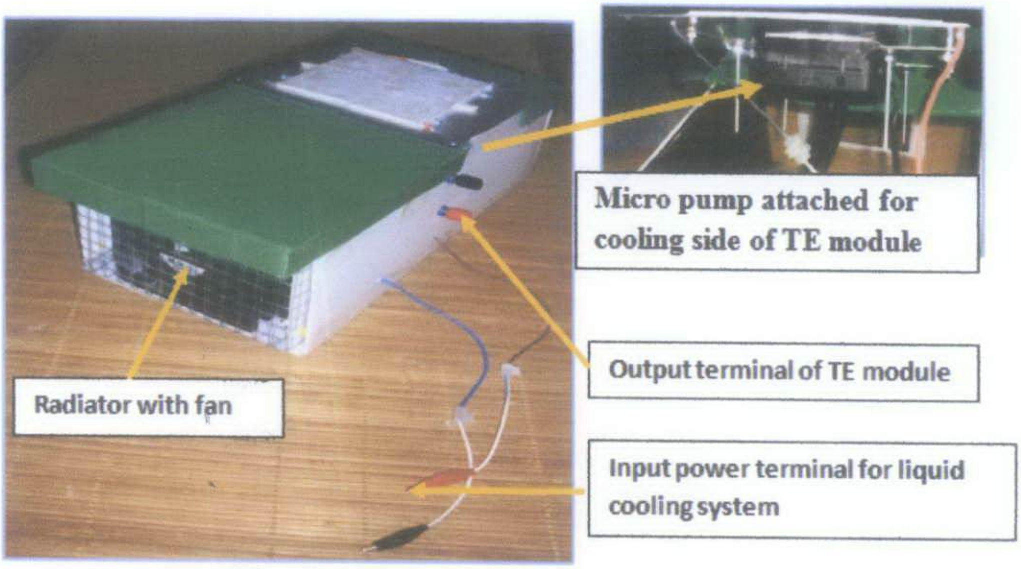
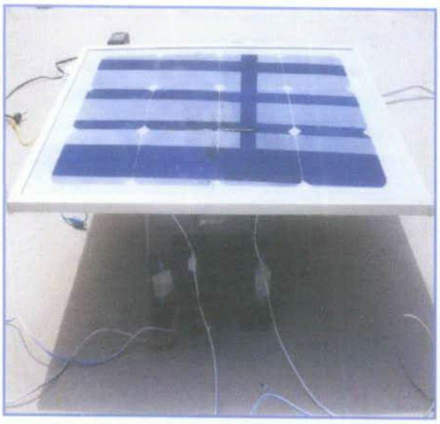


Figure 3.9: TE module with liquid cooling system construction

4 units of TE module are connected electrically in series and thermally in parallel to get higher value of voltage produced as in Figure 3.9 The voltage produced is based on the different of temperature between two layers of the semiconductor material. The aluminium plate is used as collector of heat at upper side of TE module and also at bottom side which attach to liquid cooling system as in Figure 3.9. Liquid cooling system with glycol is used to provide low temperature at cold side. This system integrates the micro pump, copper cooling plate, and radiator. The liquid block and radiator are attached to TE module and routes glycol through it to keep things cool incorporated with the micro pump.

The constraint to use liquid cooling system is the consuming of power from micro pump for circulation of propylene glycol fluid. The circulation of fluid is important to maintain the cool temperature of fluid. The fluid circulates through the radiator which is fast for heat dispersion. The liquid cooling system maintains the low temperature of cold side of TE module when the heat transferred from hot side of TE module. So, the voltage produced will be higher for the prototype of PV thermal panel with liquid cooling system.

3.5 Integration of Photovoltaic cells with Thermoelectric module



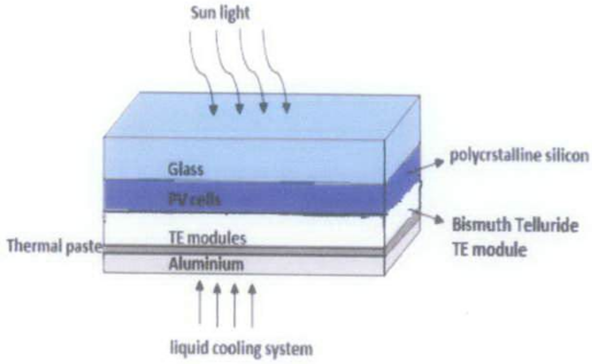


Figure 3.10: hybrid PV and TE panel Figure 3.11: Illustration of prototype panel layer

This new photovoltaic and thermoelectric hybrid panel presently exists only as prototype. So, the size will be bigger than the desired size. Most important materials are PV cell and TE module as basic element to generate electricity. Both part of PV panel and TE module constructed will be integrated together to generate electricity. The integration of these two parts produce photovoltaic thermal hybrid panel that will improve the efficiency of generating electricity.

This prototype hybrid PV thermal panel utilizes the solar radiant light and solar heat through multilayered configuration as shown in Figure 3.11. PV cell and TE module are used for electrical conversion from solar radiation and thermal energy. The glass is used on top of the prototype panel to increase the fraction of light transmitted and protection to the PV cells. Then, the cooling system attach to the aluminium layer below TE module. Thermal paste is used to improve the heat transfer from PV cell to TE module.

3.6 Prototype experiment method

The software of PASCO data studio is used to measure and record the data from the prototype panel. The equipment needed to run PACSO data studio software is voltage sensor, current sensor, temperature sensor, Science Workshop (SW)750 interface with 3 input sensor and adapter for interface power supply. The figure of all these equipment as below:

Figure 3.12: SW 750 interface

Figure 3.13: Current sensor

Figure 3.14: Voltage sensor

Figure 3.15: Temperature sensor

There are two experiments conducted in order to analyze the performance of TE module base on the temperature and PV thermal panel base on global solar radiation.

3.6.1 *Temperature different test of TE module*

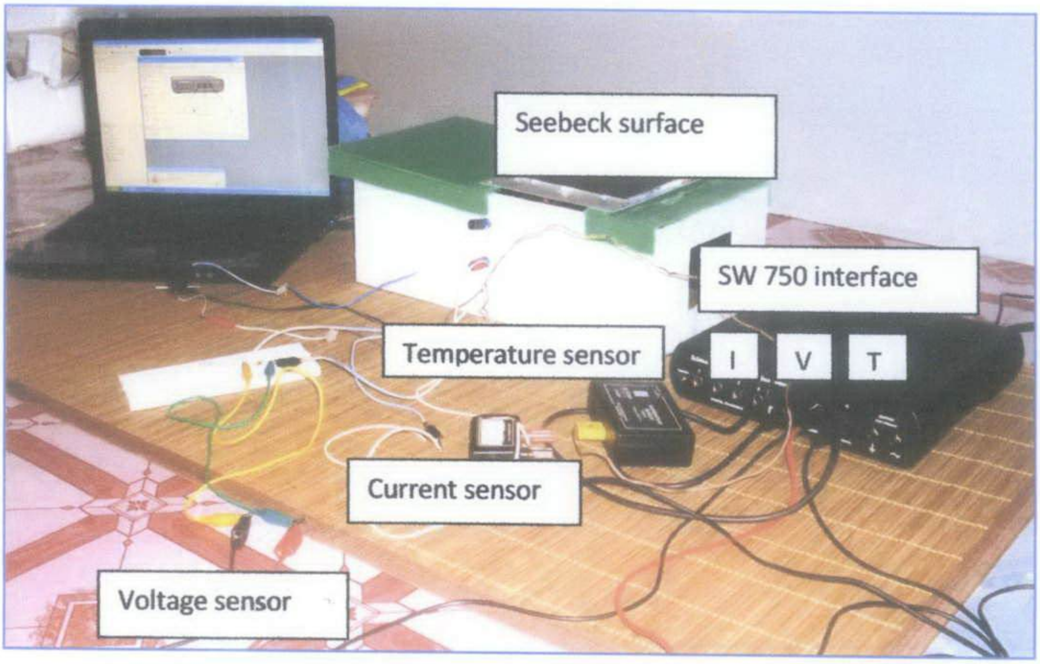


Figure 3.16: Set up to test TE performance base on temperature using PASCO data studio

The purpose of this test is to get the value output of voltage and current produced based on the difference temperature between the junctions of TE module. This experiment used PASCO Data Studio software for collecting and analysing data by using sensor system of voltage, current and temperature. The measurements are displayed in the table and graph of the data versus with time. The connection of the apparatus for this experiment is as shown in Figure 3.16. Thermocouple wire of temperature sensor attached to surface of TE module, the current sensor in series and voltage sensor in parallel connected to the load with 4.1Ω of resistance. The hot plate used as the source of heat which is representing the solar heat. The voltage is measured in parallel and current is measure in series with the load. The connection of the circuit to measure is shown in Figure 3.17.

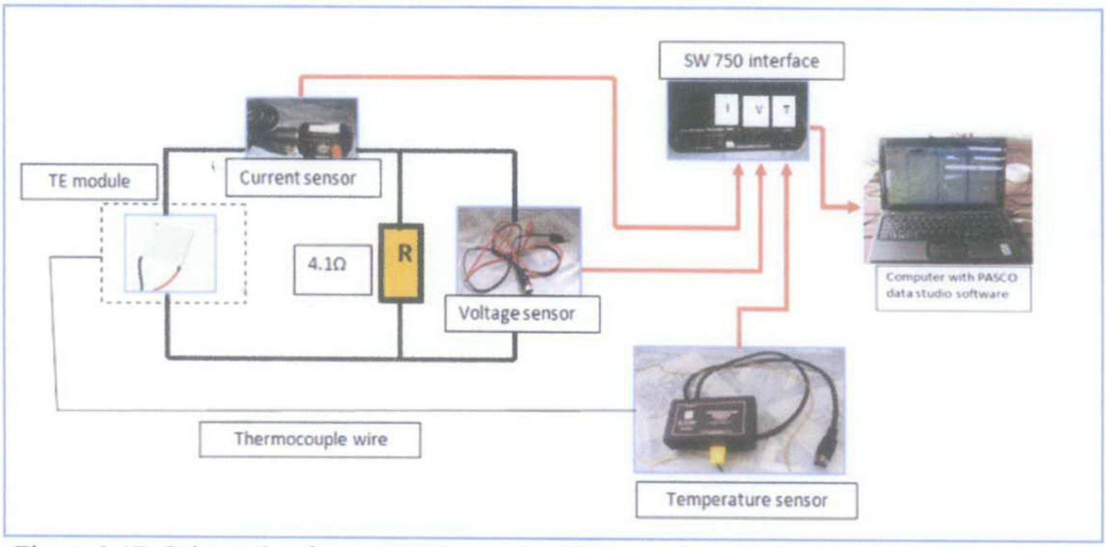


Figure 3.17: Schematic of apparatus to measure TE module output due to temperature change

3.6.2 Prototype panel efficiency test

The purpose of this test is to measure the prototype panel performance base on efficiency versus solar radiation received. The data was recorded by using PASCO data studio software with SW 750 interface, current sensor and voltage sensor. SW 750 interface only have 3 port of input sensor to record 3 different inputs at same time. So, for this experiment 4.1Ω power resistor used as the load and the measure of voltage take in parallel with the load. Two port of sensor used to measure close loop voltage for TE module and PV panel at 4.1Ω resistance. The current flow through the circuit acquired dividing the measured voltage by the resistance. Other 1 port sensor was used to measure the short circuit current of reference solar cell. Apart of pyranometer, reference solar also can be to measure the solar radiation. Reference solar cell captures the global solar radiation which required the prototype panel to be in horizontal condition. The reference solar cell obtained from solar lab and was calibrated. Then, the solar radiation measurement was taken from output curve produce by reference solar cell. The connection of the equipment during conducting this test is as shown in Figure 3.18.

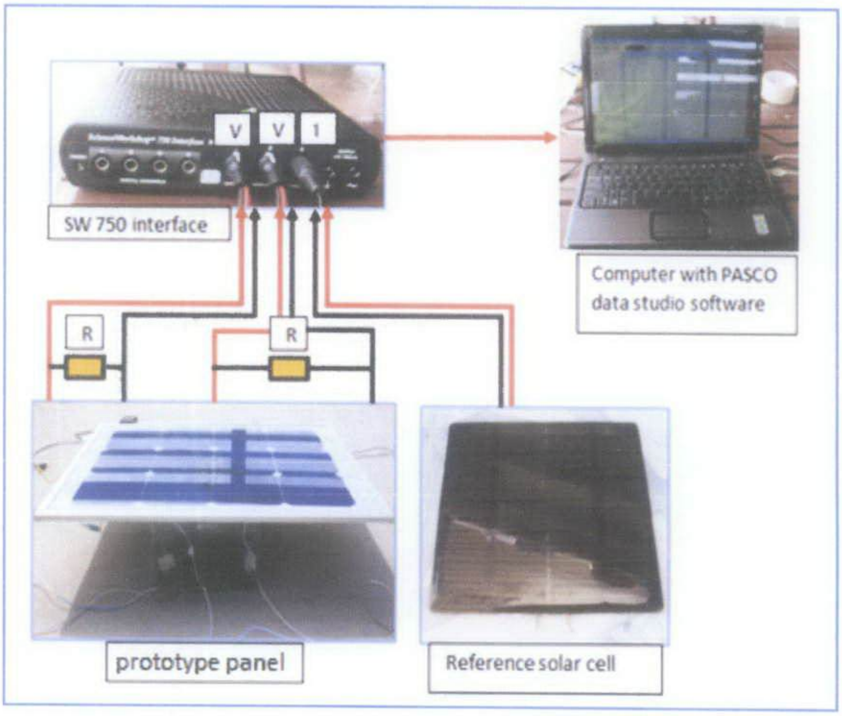


Figure 3.18: Schematic of apparatus to measure solar radiation and output from prototype panel

The efficiency of the prototype panel can be obtained base on this equation:

$$\text{Efficiency}, \eta = \frac{\text{Power produced by prototype panel}(\mathrm{W/m^2})}{\text{Solar radiation}(\mathrm{W/m^2})} \text{ x } 100\% \qquad (3.1)$$

$$\text{Power produced by prototype panel } (\mathrm{W/m^2}) = \frac{\text{Power produced by prototype panel}(\mathrm{W})}{\text{Dimension area in } \mathrm{m^2}} \qquad (3.2)$$

CHAPTER 4
RESULT AND DISCUSSION

This chapter provide the results for experimental test for the prototype of PV and TE panel. There are two types of test that has been conducted to test the performance of prototype panel due to the change of solar radiation and temperature. Then, the results have been analyzed and the discussion base on result is provided in this chapter. At the end of this chapter, the cost analysis of this project is discussed.

4.1 Temperature different test of TE module

PASCO Data Studio software is used to measure the voltage and current produce by the 4 units of TE module while the temperature is varying. In this experiment, the temperature predicted to be maximising at 70°C to 80°C during the peak sunshine period.

Thermocouple wire is attached at the surface of the prototype to take reading of temperature. Then, the voltage is measured in parallel and current is measured in series with the load with 4.1Ω resistance.

Table 4.1 show that the output voltage and current of TE module which is increase with the increase of temperature difference. The bigger temperature difference cause more electron flow from hot to cold junction of TE module and resulting bigger voltage. So, the power produced increases from 0.027W to 0.43W at 10°C and 40°C of temperature difference.

No. Exp.	Difference Temperature (dT/°C)	Voltage (V/V)	Current (I/A)	Power (P/W)
1	10	0.3	0.09	0.027
2	20	0.5	0.12	0.06
3	30	0.9	0.20	0.18
4	40	1.35	0.32	0.43

Table 4.1: TE output produce due to the different temperature

4.2 Testing for prototype panel efficiency

Global horizontal solar radiation data ware obtained from the data measured by reference solar cell which is located at solar tower within the same location with the prototype panel was installed. The connection of the sensor system with the SW 750 interface and the computer which record the measurement value by using PASCO data studio software is shown in Figure 3.18. Figure 4.1 show the real time plotting of Global Solar Radiation received during daytime from 7 am until 7 pm for 2 different days at solar tower. This measurement was recorded on 10 December 2011 and 11 December 2011. The data was taken of each 15minutes time interval.

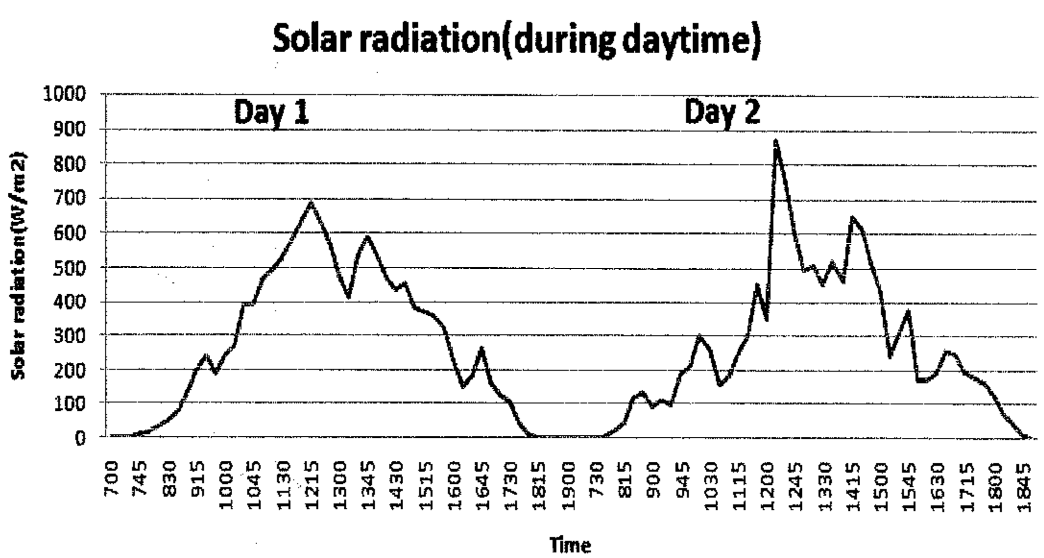


Figure 4.1: Global Solar radiation received during daytime for 2 different days

Because of limited port of input sensor port at SW 750 interface, the measurement can be taken only for PV panel close loop voltage, TE module close loop voltage and output of solar reference cell. The current flow through the PV panel and TE module obtained from dividing the voltage by resistance. The load resistance value for this experiment is 4.1Ω. The output power generated by PV panel and TE module obtained by multiply the voltage with the current. This experiment was conducted within 2 days which allocated the first day to take the reading of PV panel output and TE module without liquid cooling system. Then, the second day allocated to take the reading of PV panel output and TE module with liquid cooling system.

4.2.1 Test for prototype panel without liquid cooling system

The whole day data measurement of prototype panel output without liquid cooling system on 10 December 2011 shown in Appendices C. The output of PV panel and TE module for the selected value of solar radiation is shown in Table 4.2 for further analysis.

	PV panel			TE module		
Solar radiation(W/m^2)	**Voltage (V)**	**Current (A)**	**Output Power (W)**	**Voltage (V)**	**Current (A)**	**Output Power (W)**
109.22	2.95	0.72	2.123	0.042	0.01	0.00043
200.68	3.98	0.971	3.863	0.077	0.0188	0.001446
319.62	4.63	1.13	5.229	0.163	0.04	0.00648
411.06	5.06	1.234	6.245	0.26	0.063	0.016488
523.52	5.48	1.337	7.324	0.404	0.099	0.039809
627.02	5.71	1.392	7.952	0.54	0.132	0.071122
684.26	5.75	1.402	8.064	0.6	0.147	0.087805

Table 4.2: Output of PV panel and TE module without liquid cooling system

From Table 4.2, the output value of voltage and current for PV panel and TE module is increasing when the solar radiation is increase. TE module received more heat transfer from PV cell when the solar radiation is higher. The output power of PV panel increase from 2.123W to 8.064W and output power of TE module increase from 0.00043W to 0.0878W when solar radiation increases.

Solar radiation(W/m^2)	PV output power(W/m^2)	TE output power(W/m^2)	Total power (W/m^2)= TE +PV
109.22	11.323	0.030	11.353
200.68	20.603	0.100	20.703
319.62	27.888	0.450	28.338
411.06	33.307	1.145	34.452
523.52	39.061	2.765	41.826
627.02	42.411	4.939	47.350
684.26	43.008	6.098	49.106

Table 4.3: Output power for PV and TE in W/m^2

Table 4 show the output power of PV and TE panel converted in W/m^2 to get the panel efficiency. To convert the value, the output power of PV panel is dividing by the area of PV panel which is 0.1875m^2 and output power of TE module is dividing by the area of 4 units of TE module panel which is 0.0144m^2. Then, the total power represent the output power of prototype panel which is utilizing solar radiation and heat by using PV panel and TE module. Figure 4.2 show the increasing of PV output power in W/m^2 with solar radiation and Figure 4.3 show also the increasing of TE output power in W/m^2 with solar radiation.

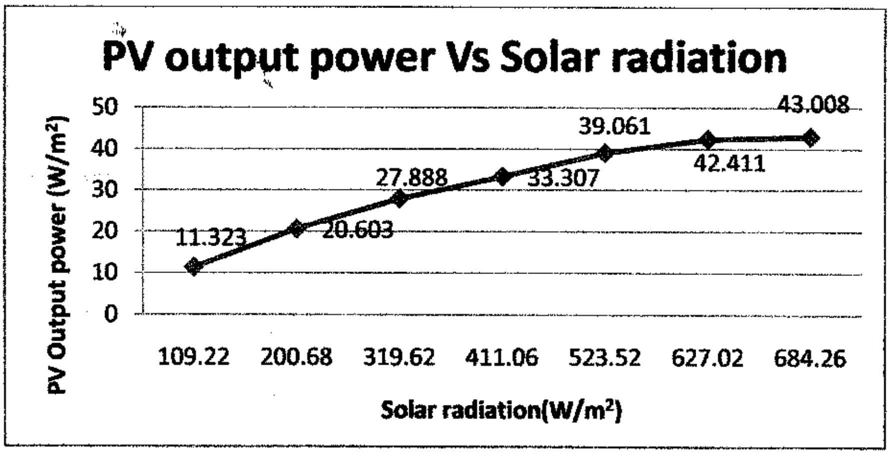


Figure 4.2: Graph of PV output power (W/m^2) Vs Solar radiation (W/m^2)

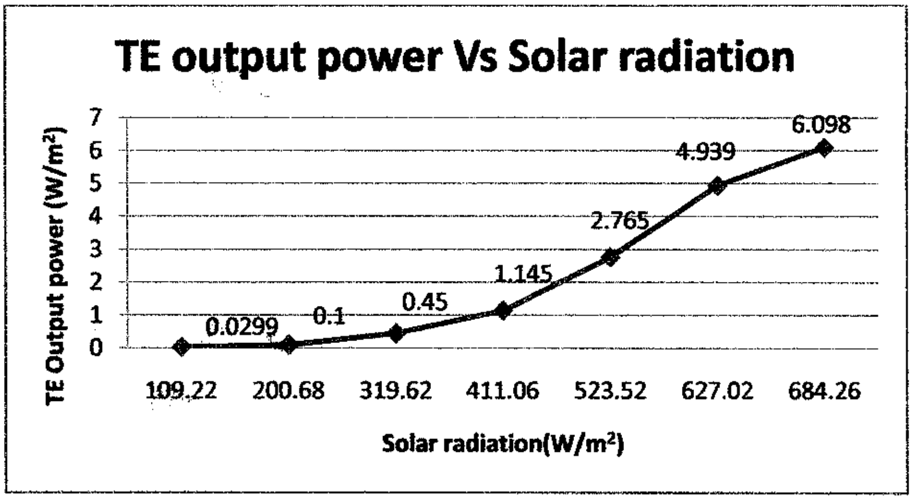


Figure 4.3: Graph of TE output power (W/m^2) Vs Solar radiation (W/m^2)

Solar radiation(W/m^2)	PV panel efficiency (%)	TE module efficiency (%)	Total efficiency (%) =TE +PV
109.22	10.367	0.027	10.394
200.68	10.267	0.05	10.317
319.62	8.725	0.141	8.866
411.06	8.103	0.279	8.382
523.52	7.461	0.528	7.989
627.02	6.764	0.787	7.551
684.26	6.285	0.891	7.176

Table 4.4: Efficiency of PV and TE with the solar radiation

Table 4.4 show the efficiency of PV panel, TE module with the solar radiation. The efficiency is obtained by dividing the received solar energy of radiation by output power in W/m^2 and multiply with 100%. The efficiency is present in percentage. Total efficiency represents the efficiency of prototype panel which is utilizing solar radiation and heat by using PV panel and TE module. From the result, it is show that PV panel efficiency decrease when solar radiation is increasing while TE module efficiency increase with solar radiation.

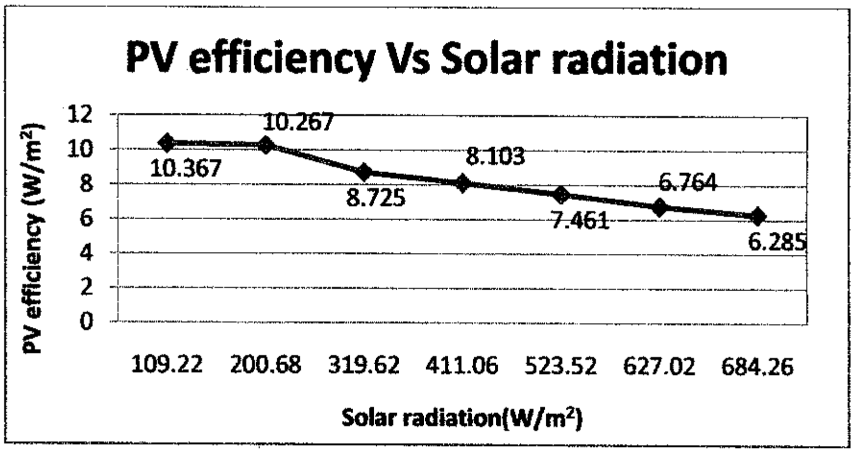


Figure 4.4: PV efficiency (%) versus solar radiation (W/m^2)

From the graph in Figure 4.4, PV efficiency is decreasing from 10.367% to 6.285% when solar radiation increase from 109.22 W/m^2 to 684.26 W/m^2 because of the increasing of temperature due to the heat energy transfer by the sun.

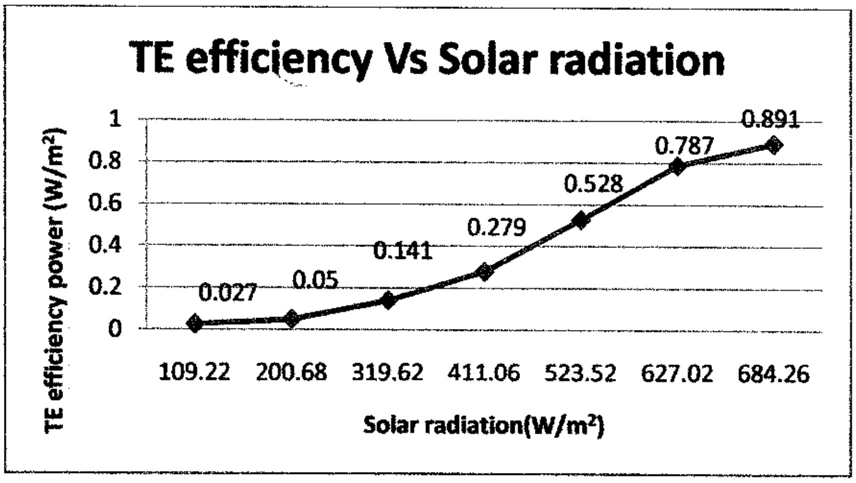


Figure 4.5: PV efficiency (%) versus solar radiation (W/m^2)

From the graph in Figure 4.5, TE module efficiency is increasing from 0.027% to 0.891% when solar radiation increases from 109.22 W/m^2 to 684.26 W/m^2. The higher solar radiation received by the PV cell, more heat transfer to TE module. More heat received by TE module, more electron flow from hot junction to cold junction resulting higher output power produced. Then, the efficiency of energy conversion of TE module also increases with the temperature.

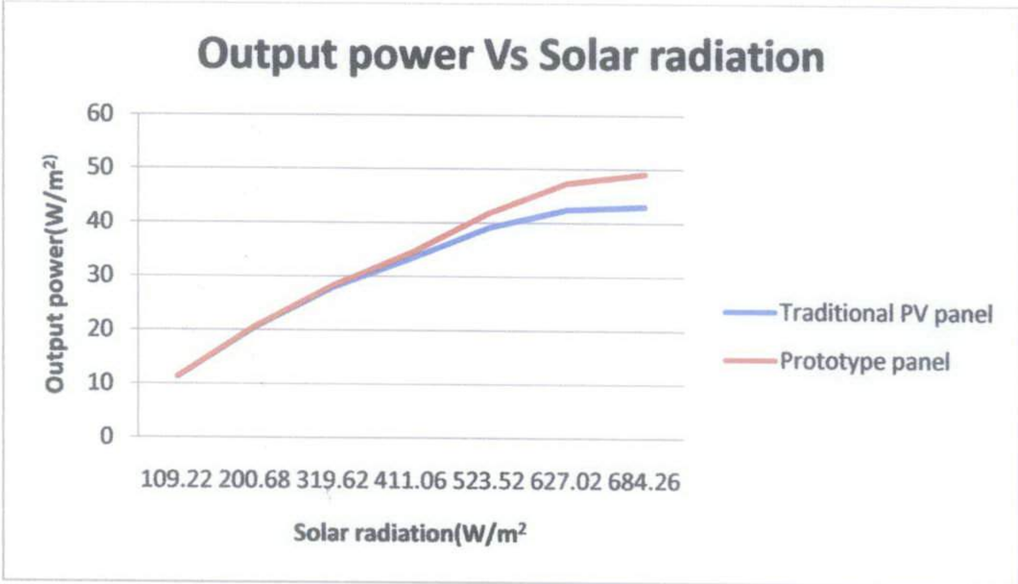


Figure 4.6: Comparison of output power between traditional PV panel and prototype panel

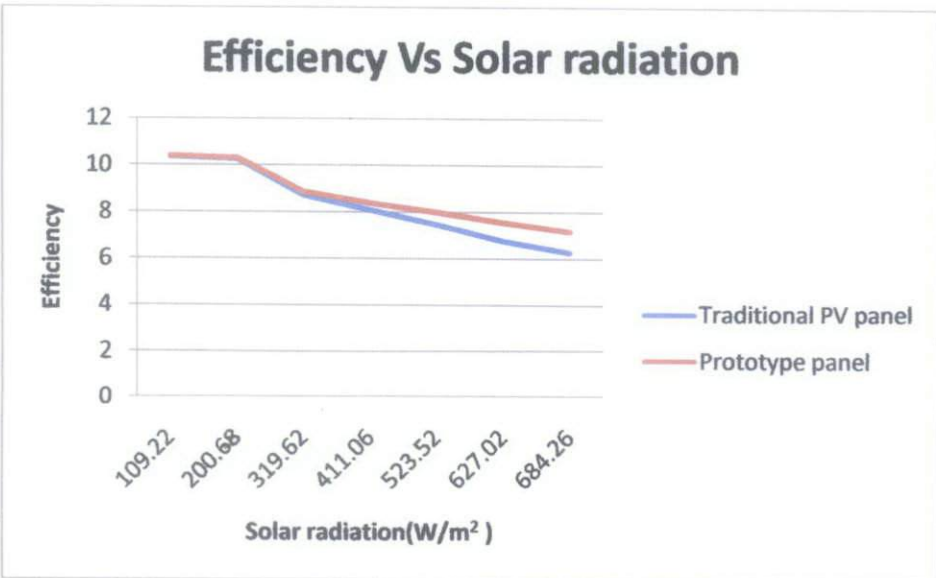


Figure 4.7: Efficiency of traditional PV panel and prototype panel

The graph in Figure 4.6 shows the improvement of prototype panel output power from traditional PV panel. The output power increase by 6.098 W/m^2 from

43.008W/m^2 at 684.26 W/m^2 of solar radiation which is contribute for higher efficiency with 0.891% improvement from 6.285% the as shown in Figure 4.7.

4.2.2 Test for prototype panel integrated with liquid cooling system

Liquid cooling system integrated with PV thermal panel to increase the voltage produce. The whole day data measurement of PV thermal panel with liquid cooling system output is shown in Appendix D. The output of PV panel and TE module for the selected value of solar radiation is shown in Table 4.5 for further analysis.

	PV panel			TE module + liquid cooling system		
Solar Radiation(W/m^2)	**Voltage (V)**	**Current (A)**	**Output Power (W)**	**Voltage (V)**	**Current (A)**	**Output Power (W)**
112.89	3.010	0.734	2.209	0.085	0.021	0.002
191.56	3.890	0.950	3.700	0.188	0.046	0.009
301.97	4.580	1.117	5.116	0.329	0.800	0.026
428.52	5.100	1.244	6.334	0.534	0.130	0.070
507.65	5.450	1.329	7.245	0.600	0.146	0.088
601.12	5.680	1.385	7.869	0.810	0.198	0.160
752.01	5.900	1.439	8.490	1.080	0.263	0.284
868.08	6.310	1.539	9.710	1.260	0.307	0.387

Table 4.5: Output of PV panel and TE module with liquid cooling system

From the Table 4.5, the voltage and current produce by the PV panel increase as the solar radiation increase. So, output power also increase from 2.209W at 112.89W/m^2 to 9.71W at 868.08W/m^2. The voltage and current produced by TE module also increase when solar radiation increase. This gives the increasing of output power from 0.002W at 112.89W/m^2 of solar radiation to 0.387W at 868.08W/$m^2$of solar radiation.

Solar radiation (W/m^2)	PV output power(W/m^2)	TE output power (W/m^2)	Total power (W/m^2) = TE +PV
112.89	11.789	0.122	11.911
191.56	19.68	0.600	20.280
301.97	27.286	1.833	29.119
428.52	33.830	4.833	38.663
507.65	38.630	6.100	44.730
601.12	41.967	11.113	53.080
752.01	45.280	19.756	65.036
868.08	51.933	26.890	78.823

Table 4.6: Output power for prototype panel (using liquid cooling system) in W/m^2

The power output was converted into W/m^2 to find the efficiency of PV panel and TE module. The prototype panel utilize both solar radiation light and heat. So, the total power of PV panel and TE module represent output power of prototype panel. Output power of prototype panel increase from 11.911 W/m^2 solar radiation to 78.823 W/m^2 when solar radiation increase. The increasing of PV output power and TE output power due to the solar radiation is shown in Figure 4.8 and Figure 4.9.

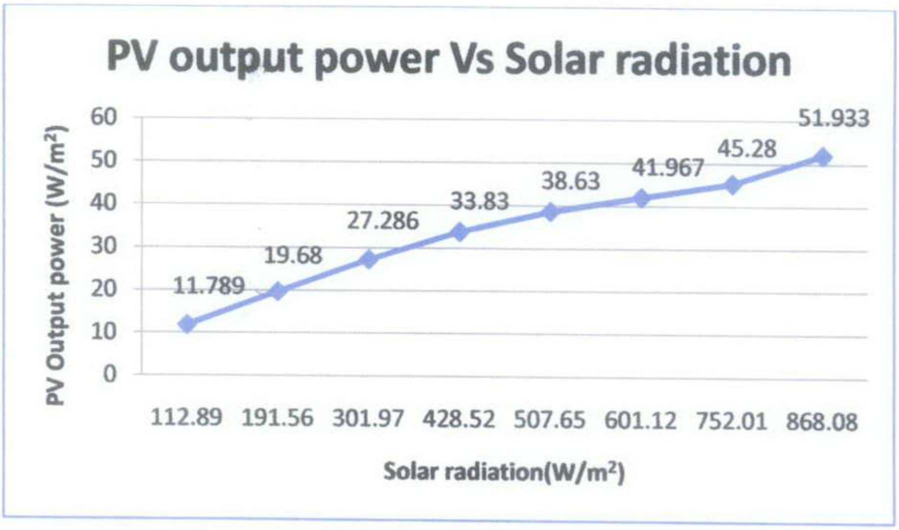


Figure 4.8: Graph of PV output power (W/m^2) with solar radiation (W/m^2)

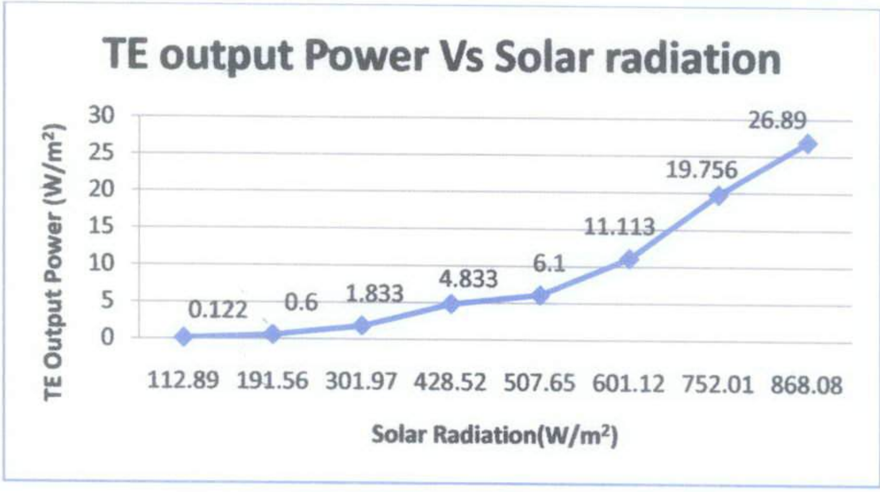


Figure 4.9: Graph of TE (with liquid cooling system) output power (W/m^2) with solar radiation (W/m^2)

Solar radiation(W/m^2)	PV panel efficiency (%)	TE module efficiency (%)	Total efficiency (%) =TE +PV
112.89	10.440	0.108	10.548
191.56	10.270	0.312	10.582
301.97	9.040	0.607	9.643
428.52	7.900	1.127	9.027
507.65	7.600	1.200	8.800
601.12	6.980	1.840	8.820
752.01	6.020	2.627	8.647
868.08	5.970	3.098	9.064

Table 4.7: Efficiency of PV and TE (using liquid cooling system) with the solar radiation

By dividing the output power per area of m^2 by the solar radiation received from the sun, the efficiency of the PV panel and TE module was obtained. The efficiency of PV panel decrease from 10.44% to 5.97% when solar radiation increase from112.89W/m^2 to 868.08W/m^2. This can be seen in Figure 4.10. Then, the efficiency of TE module increasing from 0.108% to 3.098% when solar radiation increase from112.89W/m^2 to 868.08W/m^2. This can be seen in Figure 4.11.

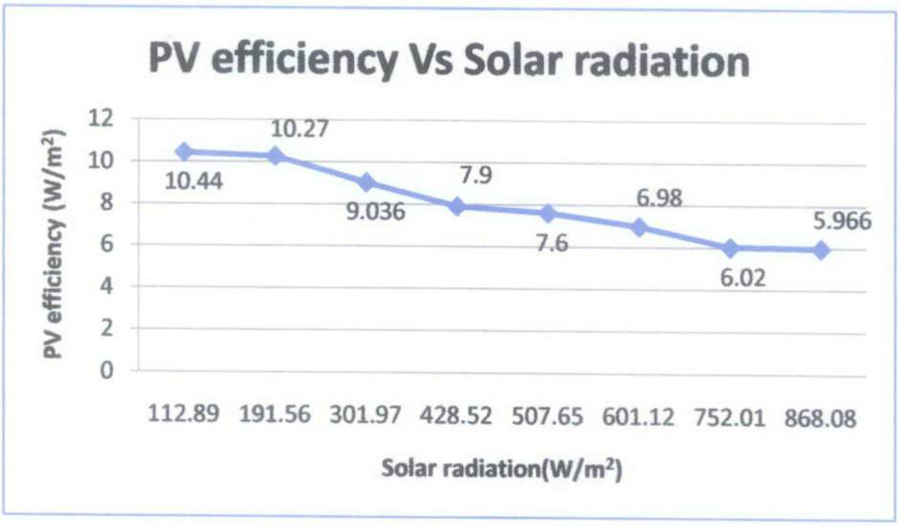


Figure 4.10: PV efficiency (%) versus solar radiation (W/m^2)

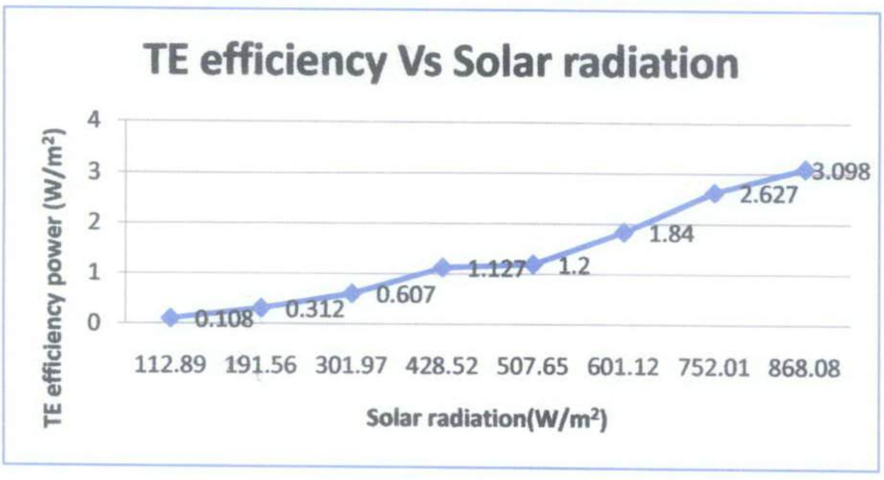


Figure 4.11: TE (using liquid cooling system) efficiency (%) versus solar radiation (W/m^2)

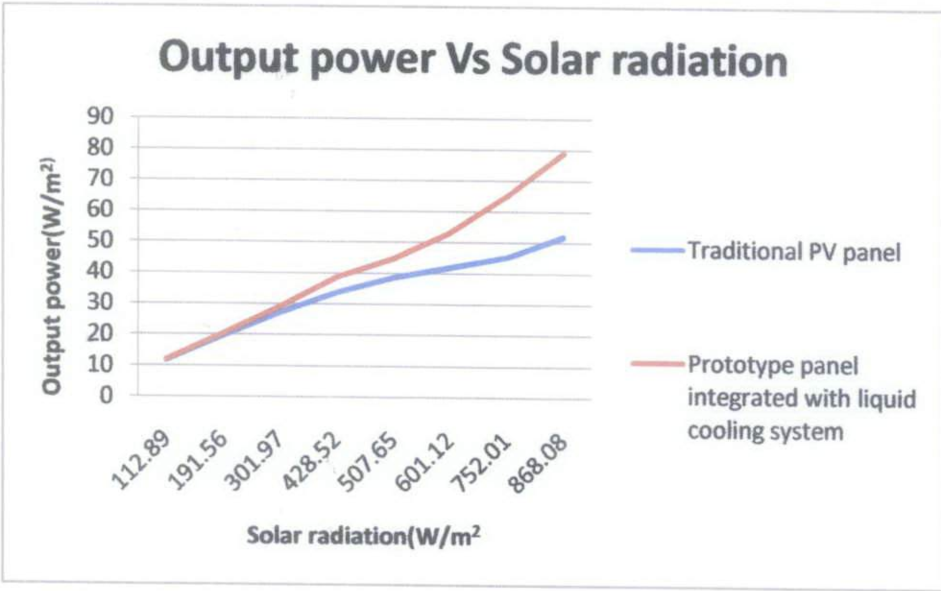


Figure 4.12: Comparison of output power between traditional PV panel and prototype panel (using liquid cooling system)

Graph in Figure 4.12 show the comparison of traditional PV panel output power in W/ m^2 with the prototype panel. This prototype panel was attached with the liquid cooling system. So, the output power produced by TE module with is higher compare to output power of TE module without TE module because of lower temperature at cold junction of TE module. This PV thermal panel with liquid cooling system output power increase by 26.89W/m^2 at 868.08W/m^2 solar radiation.

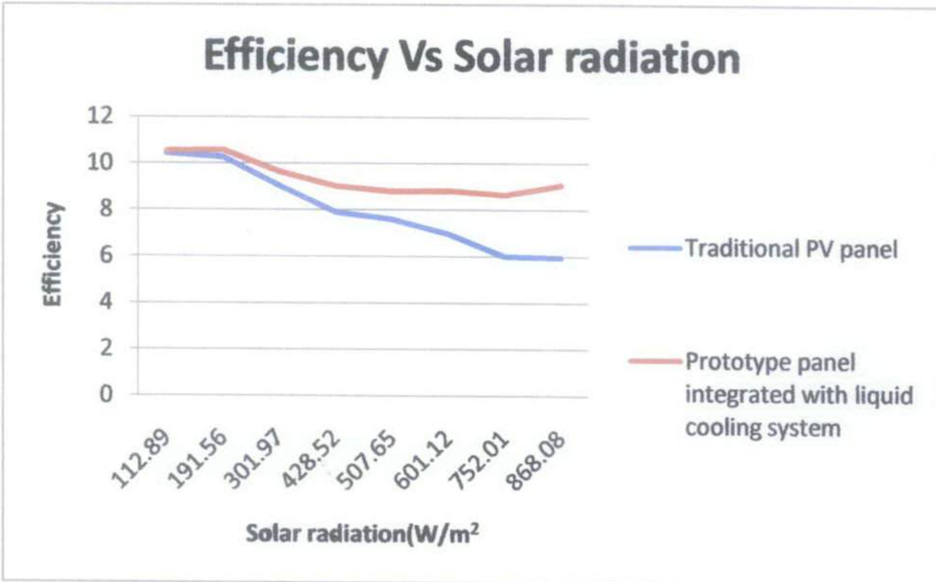


Figure 4.13: Efficiency of traditional PV panel and prototype panel (using liquid cooling system)

Figure 4.13 show the graph of comparison of traditional PV panel efficiency in W/ m^2 with the prototype panel which integrated with liquid cooling system. The efficiency of traditional PV panel keeps decreasing with the increasing value of solar radiation. By apply TE module with liquid cooling system, the efficiency increasing about 3% from traditional PV panel at 868.08W/m^2solar radiation.

4.2.3 Comparison of prototype panel performance before and after integrate with liquid cooling system

Solar radiation (W/m^2)	PV panel output power (W/m^2)	Prototype panel output power (W/m^2)	Solar radiation (W/m^2)	PV panel output power (W/m^2)	Prototype panel with liquid cooling system output power (W/m^2)
109.22	11.320	11.350	112.890	11.790	11.910
319.62	27.890	28.338	301.970	27.290	29.120
627.02	42.411	47.350	601.120	41.970	53.080

Table 4.8: Output power comparison between 3 types of solar panel

The comparable solar radiation reading about 100W/m^2, 300W/m^2, and 600W/$m^2$for a different day is taken for further analysis is shown in Table 4.8. There are three type of panel that been compared in this table which is traditional PV panel, prototype panel with and without liquid cooling system. The result shows that by output power of prototype panel is improved from traditional PV panel. However, output power of prototype panel attached by liquid cooling system is improved which gives 53.08 W/m^2at 601.12 W/$m^2$of solar radiation.

Solar radiation (W/m^2)	**PV panel efficiency**	**Prototype panel efficiency**	**Solar radiation (W/m^2)**	**PV panel efficiency**	**Prototype panel with liquid cooling system efficiency**
109.22	10.367%	10.394%	112.89	10.44%	11.91%
319.62	8.725%	8.866%	301.97	9.036%	9.643%
627.02	6.764%	7.551%	601.12	6.98%	8.82%

Table 4.9: Efficiency comparison between 3 types of solar panel

The comparable solar radiation reading at different days is taken for further analysis as shown in Table 4.9. Prototype panel give the improvement of efficiency compare to traditional PV panel with 0.79% from 6.76% to 7.55% at 627.02W/ m^2 of solar radiation. By integrated prototype panel with liquid cooling system, the better improvement of efficiency is obtained. Prototype panel with liquid cooling system give improvement of 1.84% of efficiency from traditional PV panel from 6.98% to 8.82% of efficiency at 601.12W/m^2 of solar radiation.

4.3 Power balance check

The purpose of this test is to check the balance between power consumed by liquid cooling system and power generated by TE module. The operating current for micro pump is 30mA and silent fan is 20mA which give total current is 50mA. The voltage rating for micro pump and silent fan is 12V. For this prototype, 4 unit of TE module is use for the analysis from the output power generated. The output power generated by 4 units of TE module is quite low compare to the power consumed by the liquid cooling system. But, if more TE module is used more power generated and can be balanced with the power consumed. So, the power produced is converted into $1m^2$ of area for further analysis.

The liquid cooling system is quite efficient to be used at higher temperature to cool TE module surface. From the radiation measurement on 10 December 2011 and 11 December 2011, the solar radiation is high at 10 am to 3 pm with about 300W/$m^2$to 850W/m^2. So, the average for the whole 5 hours is about 500W/m^2. This is the estimation power balance check for TE module and liquid cooling system:

- Power consumed by liquid cooling system
  = 12V x 50mA=0.6W
- Power generated by TE module at 500 W/m^2 (Appendix D)
  =0.101W

#Assume that the same cooling system used for $1m^2$of area:

- Power generated by TE module with liquid cooling system at 500W/m^2
  =7.01W/m^2
- Power balance check = Power generated by TE – Power consumed
  =7.01 – 0.6 = 6.41W/m^2

4.4 Cost analysis

Item		Cost (RM/m^2)		
		PV	**PV + TE**	**PV + TE + liquid cooling system**
PV layer	Glass Multi layer back sheet PV cells Aluminium frame	RM25 RM20 RM1280 RM15	RM25 RM20 RM1280 RM15	RM25 RM20 RM1280 RM15
TE layer	TE module $\mathbf{Bi_2Te_3}$ (4 unit)	0.00	RM 5500	RM 5500
Liquid cooling system	Aluminium plate Silent fan, radiator, micro pump and tube	0.00	0.00	RM20 RM 300
Total		**RM1340**	**RM6840**	**RM7160**

Table 4.10: Cost analysis of 3 type of panel

This cost analysis is estimated in $1m^2$ of area for the comparable size of TE module and PV panel. This is the cost analysis base on materials purchase for main material and fabrication of prototype. The dimension of PV cells is dimension 12.5cm × 12.5 cm and Bismuth Telluride of TE module is dimension 6cm × 6cm for each unit.

TE module is very costly compare to PV cells. It is not very cost-efficient based on Table 4.10. However, TE technology currently is in fast development due to the high potential for power generating system. Bi_2Te_3 material of TE can be replaced by SiGe Quantum Well material which the raw material 10 times lower in cost and can produce 10 times more output power [32]. The emerging of nanotechnology of TE material contributes for higher efficiency.

Then, liquid cooling system seems expensive because it is used for 4 units of TE module only. If the prototype use bigger size of PV cell and more number of TE modules such as in $1\mathbf{m}^2$ of area, liquid cooling system will be more cost efficient.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion:

This PV thermal panel is the modification of PV technology system by integrates two hybrid systems of PV panel and TE module. This PV thermal panel utilize solar radiation and heat directly from the sun as source of electricity generation. The cooling liquid system is attached at the cold side of thermoelectric module to maintain lower temperature and give greater different of temperature and generate more electricity.

The efficiency of PV thermal can be increased to up to 0.79% without cooling system and 1.84% with integration of cooling system from traditional PV panel at 600W/$m^2$of solar radiation. Result also show that at 868 W/m^2solar radiation, PV thermal panel with liquid cooling system can improve efficiency up to 3%.

The fast development of research in TE material gives the big potential for better output of this prototype panel. The use of high efficiency of Silicon Germanium, SiGe Quantum Well TE module could contribute to electricity generation with overall higher efficiency.

5.2 Recommendation:

There are several recommendations that can improve the result of this project:

a) It is highly recommended to replace Bismuth Telluride type of TE module used in this project to Silicon Germanium (SiGe) Quantum Well which has higher efficiency that could contribute for higher overall efficiency of PV thermal panel. SiGe Quantum Well material has 5 times higher values of ZT which indicate the material efficiency compare to Bismuth telluride material. Then, the cost of raw material for Silicon Germanium Silicon Quantum Well is lower than Bismuth Telluride.

b) This project use polycrystalline silicon of PV cell which is not the best material for this PV thermal panel. So, it is recommended to use monocrystalline silicon of PV cells which have higher efficiency up 18%. So, the better output can be produce by the prototype panel.

c) The measurement of data is recommended to be record for smaller time interval. Instead of 15 minutes time interval, the measure of 1 minute's time interval should be better for accuracy of measurement. Bigger size of time interval could possibly give bigger error of measurement. Then, the data record recommended being measure for 1 month instead of 2 days. So, more accurate analysis can be done for more data recorded.

d) The power output of prototype panel is varying with solar radiation received. So, battery and charge controller needed for storage before supply to the load. The inverter required for AC load. The, the battery and prototype panel need to be sizing and estimate with the load to be used.

REFERENCES

[1] Suchitra Sriram, Asia Pacific Energy Practice," Solar Power in Malaysia – Impediments to Growth", 25 Apr 2006 from http://www.frost.com/prod/servlet/market-insight-top.pag?docid=67575287

[2] K. Sopian, M.Y.Othman, B. Yatim, and W.R.W. Daud, "Future Directions in Malaysian Environmen Friendly Renewable Energy Technologies Research and Development", Universiti Kebangsaan Malaysia, May 2005 Volume 1, pg 30-36

[3] "PHOTOVOLTAIC SOLAR Electricity from the sun," 20 June 2011 from http://www.originenergy.com.au/2029/Photovoltaic-cells

[4] V.Ryan, "what is photovoltaic", 2005-2007 from http://www.technologystudent.com/energy1/solar5.htm

[5] Gil Knier, "How do photovoltaic work", 2002, from http://science.nasa.gov/science-news/science-at-nasa/2002/solarcells/

[6] Chengqing Yuan; Conglin Dong; Liangliang Zhao; Xinping Yan, Sch. of Energy & Power Eng., Wuhan Univ. of Technol., Wuhan, China, "Marine environmental damage effects of solar cell panel","22", Prognostics and Health Management Conference. 17 February 2010, pg 1-5

[7] Sims Web Developer, "Solar PV", 2007, 22 June 2011 from http://www.newgenerationenergy.co.uk/solar-pv.htm

[8] WSE technologies wininng with solar energy, "Solar panels", 21 June 2011, from http://www.wsetech.com/solarpanels.php

[9] Free Sun Power, “Basics tutorial-solar panels”, 20 June 2011 from http://www.freesunpower.com/solarpanels.php

[10] Narayanan, S.; Wenham, S. R.; Green, M. A., Solar Photovoltaic Laboratory, Joint Microelectronics Research Centre, University of New South Wales, Kensington, Australia 2033 , “High efficiency polycrystalline silicon solar cells using phosphorus pretreatment”, Applied Physics Letters conference, Volume: 48 Issue:13, 18 June 2009, pg 873 – 875

[11] Narayanan, S, Wenham, S.R, Green, M.A.,Joint Microelectron. Res. Centre, New South Wales Univ., Kensington, NSW, “17.8-percent efficiency polycrystalline silicon solar cells”, “3” Electron Devices, IEEE Transactions on, Volume: 37 Issue:2, 06 August 2002, pg 382-384

[12] Eric,“Solar Cells Shedding a little light on photovoltaics”, 2002 10 July , 2003 from http://www.solarbotics.net/starting/200202_solar_cells/200202_solar_cell_types.html

[13] Yoshinori Yukimoto, “Amorphous solar cell”, 1986, 12 April 1988 from http://www.google.com.my/patents?hl=en&lr=&vid=USPAT4737196&id=LSc8AAAAEBAJ&oi=fnd&dq=amorphous+solar+cell&printsec=abstract#v=onepage&q&f=false

[14] Hahn Meitner, Institute Berlin,”Solar cell”, 5 December 2010 from http://www.pvresources.com/en/solarcells.php

[15] PV cycle,”material used for photovoltaic cells” 23 June 2011 from http://www.pvcycle.org/index.php?id=7

[16] John Drake Services, Inc.” Photovoltaic module construction”, 23 June 2011 from http://www.solarseller.com/photovoltaic_module_information_page_.htm

[17] Peter Benze, "Solar PV module component", 2 Februari 2011 from http://drbsquared.wordpress.com/2011/02/02/solar-pv-module-components/

[18] George W. Crabtree and Nathan S. Lewis, "Solar Energy Conversion", March 2007, pg 37 from http://ptonline.aip.org/journals/doc/PHTOADft/vol_60/iss_3/37_1.shtml?bypassSSO=1

[19] Crabtree, G.W. and N.S. Lewis, Solar Energy Conversion. Physics Today, 2007. 60(3): pg. 37-42

[20] ITSadmin,"Solar (Thermoelectric) Energy Conversion", 3 March 2007 from http://www.its.org/node/4920

[21] "TEG Power," 21 June 2011 from http://www.tegpower.com/

[22] Juan Carlos Parejo FAMFAMFAM, "Thermoelectric helicopter with siren", 2008, 24 March 2009 from http://www.petervaldivia.com/technology/projects/helicopter/index.php

[23] New Physical Model for Thermoelectric Generators, Laboratory of Electrical Instrumentation, Department of Microsystems Engineering (IMTEK), Albert-Ludwigs-University" t Freiburg, D-79110, Freiburg, Germany, 2009.

[24] Ospov, E.V, Aulus, A. "Semicond. Phys. Ins, Vitnius", Thermoelectric, 1997, 6 August 2002, pg 757-760

[25] "Thermoelectric energy conversion: conversion of heat into electrical energy or vice versa", 22 June 2011 from http://kleinke.uwaterloo.ca/te.html

[26] Recent Concepts in Thermoelectric Power Generation, Gao Min and D M Rowe, School of Engineering, Cardiff University, Cardiff, United Kingdom, 21st International Conference on Thermoelectronics 2002.

[27] Dennis L Feucht , "Solar Thermoelectric Technology". The Relative Merits of Thermoelectric Generation and Storage, Part 1

[28] Red and Anna Stone, "Solar Thermal Conversion", September 3, 2009, Part 2

[29] Yona, A. Senjyu, T. Dept. of Electr. & Electron. Eng., Univ. of the Ryukyus, Nishihara, Japan, "One-Day-Ahead 24-Hours Thermal Energy Collection Forecasting Based on Time Series Analysis Technique for Solar Heat,"Energy Utilization SystemTransmission & Distribution Conference & Exposition: Asia and Pacific,26-30 Oct. 2009, pg 1-4

[30] Richard E. Crane, Harold G. Lorsch, Richard L. Oswald, Franklin Research Center, Philadelphia, PA "Thermal storage of off-peak electrical energy in solar heating and cooling system," Decision and Control including the 17th Symposium on Adaptive Processes, 1978 IEEE Conference on, 02 April 2007, Volume : 17, pg 197 - 202

[31] Boerdijk, A.H, "N.V. Philips Gleolampenfabrienken, Eindhoven", Netherland. Journal of Applied physic, issue 38, volume 32,29 August 2009, pg. 1584-1589

[32] Thermoelectric Developments for Vehicular Applications, John W. Fairbanks, Freedom CAR and Vehicle Technologies Energy Efficiency and Renewable Energy US Department of Energy, Washington, August 24, 2006

APPENDIX A

GANTT CHART FYP 1

TITLE	WEEK													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Select the topics from list														
Confirmation of the topic														
Extended Proposal preparation														
Extended proposal submission														
Proposal defence														
Fabrication														
Justifying and purchasing the material														
Fabricate PV panel and TE module														
Analysis for initial result														
Interim report														

Process

Key mile stone

APPENDIX B

GANTT CHART FYP 2

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Integrate PV module and TE module															
4	Finishing the prototype of PV thermal panel															
5	Test and analysis the final prototype product															
6	Submission progress report															
7	Submission draft report															
8	Submission of Final Report (soft copy)															
9	VIVA															
10	Submission of Final Report (hard copy)															

Process

Key mile stone

APPENDIX C

Date: 10 December 2011

Time	Radiation (W/m2)	Traditional PV panel					PV thermal panel				
		Voltage (V)	Current (A)	Output power (W)	Power (W/m^2)	Efficiency (%)	Voltage (V)	Current (A)	Output power (W)	Power (W/m^2)	Efficiency (%)
700	0	0	0	0	0	0	0	0	0	0	0
715	0	0	0	0	0	0	0	0	0	0	0
730	0.34	0	0	0	0	0	0	0	0	0	0
745	10.17	0.4	0.097561	0.039024	0.20813	2.046510141	0.03	0.007317	0.00022	0.015244	0.149891
800	18.03	0.7	0.170732	0.119512	0.637398	3.535210061	0.07	0.017073	0.001195	0.082995	0.460314
815	33.45	1.2	0.292683	0.35122	1.873171	5.599912501	0.017	0.004146	7.05E-05	0.004895	0.014634
830	50.49	2.15	0.52439	1.127439	6.013008	11.90930507	0.024	0.005854	0.00014	0.009756	0.019323
845	73	2.5	0.609756	1.52439	8.130081	11.13709767	0.032	0.007805	0.00025	0.017344	0.023759
900	133.96	3.27	0.797561	2.608024	13.90946	10.38329607	0.052	0.012683	0.00066	0.045799	0.034189
915	200.68	3.98	0.970732	3.863512	20.6054	10.26778871	0.077	0.01878	0.001446	0.100423	0.050042
930	242.88	4.22	1.029268	4.343512	23.1654	9.537795773	0.092	0.022439	0.002064	0.14336	0.059025
945	189.67	3.86	0.941463	3.634049	19.38159	10.21858675	0.068	0.016585	0.001128	0.07832	0.041293
1000	240.61	4.21	1.026829	4.322951	23.05574	9.582203498	0.093	0.022683	0.00211	0.146494	0.060884
1015	267.58	4.39	1.070732	4.700512	25.0694	9.368935785	0.115	0.028049	0.003226	0.224001	0.083714
1030	390.08	4.97	1.212195	6.02461	32.13125	8.237092912	0.131	0.031951	0.004186	0.290667	0.074515
1045	388.55	4.93	1.202439	5.928024	31.61613	8.136952794	0.221	0.053902	0.011912	0.827253	0.212908
1100	464.99	5.25	1.280488	6.722561	35.85366	7.710630021	0.329	0.080244	0.0264	1.83335	0.394277
1115	491.42	5.36	1.307317	7.00722	37.37184	7.604866997	0.366	0.089268	0.032672	2.268902	0.461703
1130	523.52	5.48	1.336585	7.324488	39.06393	7.461784642	0.404	0.098537	0.039809	2.764499	0.52806
1145	572.38	5.6	1.365854	7.64878	40.7935	7.126995341	0.471	0.114878	0.054108	3.75747	0.656464
1200	627.02	5.71	1.392683	7.95222	42.41184	6.76403263	0.54	0.131707	0.071122	4.939024	0.787608

1245	568.42	5.58	1.360976	7.594244	40.50263	7.12547661	0.479	0.116829	0.055961	3.886196	0.683684
1300	478	5.31	1.295122	6.877098	36.67785	7.673191142	0.348	0.084878	0.029538	2.05122	0.429125
1315	411.06	5.06	1.234146	6.24478	33.3055	8.102344168	0.26	0.063415	0.016488	1.144986	0.278545
1330	534.02	5.3	1.292683	6.85122	36.53984	6.842409909	0.411	0.100244	0.0412	2.861128	0.535772
1345	589.13	5.61	1.368293	7.676122	40.93932	6.9491143	0.49	0.119512	0.058561	4.066734	0.690295
1400	537.44	5.52	1.346341	7.431805	39.63629	7.375017245	0.423	0.103171	0.043641	3.03064	0.563903
1415	473.08	5.3	1.292683	6.85122	36.53984	7.723817832	0.336	0.081951	0.027536	1.912195	0.404201
1430	435.98	5.12	1.24878	6.393756	34.10003	7.821467159	0.286	0.069756	0.01995	1.385434	0.317775
1445	455.76	5.2	1.268293	6.595122	35.17398	7.717654849	0.309	0.075366	0.023288	1.617226	0.354841
1500	380.3	4.9	1.195122	5.856098	31.23252	8.212600664	0.219	0.053415	0.011698	0.812348	0.213607
1515	371.68	4.89	1.192683	5.83222	31.10517	8.368804007	0.217	0.052927	0.011485	0.797578	0.214587
1530	358.13	4.81	1.173171	5.642951	30.09574	8.40357966	0.193	0.047073	0.009085	0.630911	0.176168
1545	319.62	4.63	1.129268	5.228512	27.8854	8.724547392	0.163	0.039756	0.00648	0.450017	0.140797
1600	223.14	4.41	1.07561	4.743439	25.29834	11.33743007	0.86	0.209756	0.18039	12.5271	5.614009
1615	148.25	3.5	0.853659	2.987805	15.93496	10.74870782	0.06	0.014634	0.000878	0.060976	0.04113
1630	181.39	3.78	0.921951	3.484976	18.58654	10.24672616	0.07	0.017073	0.001195	0.082995	0.045755
1645	264.23	4.31	1.05122	4.530756	24.16403	9.145075321	0.112	0.027317	0.00306	0.212466	0.08041
1700	160.99	3.62	0.882927	3.196195	17.04637	10.5884676	0.065	0.015854	0.00103	0.071562	0.044451
1715	122.68	3.23	0.787805	2.54461	13.57125	11.06231825	0.052	0.012683	0.00066	0.045799	0.037332
1730	109.22	2.95	0.719512	2.122561	11.32033	10.36469987	0.042	0.010244	0.00043	0.029878	0.027356
1745	41.78	2.01	0.490244	0.98539	5.255415	12.57878084	0.02	0.004878	9.76E-05	0.006775	0.016216
1800	12.45	0.4	0.097561	0.039024	0.20813	1.671727561	0.004	0.000976	3.9E-06	0.000271	0.002177
1815	0.27	0	0	0	0	0	0	0	0	0	0
1830	0.34	0	0	0	0	0	0	0	0	0	0
1845	0	0	0	0	0	0	0	0	0	0	0
1900	0	0	0	0	0	0	0	0	0	0	0

APPENDIX D

Date: 11 December 2011

		Traditional PV panel					PV thermal panel + liquid cooling system				
Time	Radiation (W/m2)	Voltage (V)	Current (A)	Output power (W)	Power (W/m^2)	Efficiency (%)	Voltage (V)	Current (A)	Output power (W)	Power (W/m^2)	Efficiency (%)
700	0	0	0	0	0	0	0	0	0	0	0
715	0.32	0	0	0	0	0	0	0	0	0	0
730	0.09	0	0	0	0	0	0	0	0	0	0
745	6.12	0.2	0.04878	0.009756098	0.05203252	0.85020458	0.01	0.002439	2.439E-05	0.001694	0.027676
800	19.67	0.9	0.219512	0.197560976	1.053658537	5.35667787	0.015	0.003659	5.4878E-05	0.003811	0.019375
815	41.15	1.9	0.463415	0.880487805	4.695934959	11.4117496	0.03	0.007317	0.00021951	0.015244	0.037045
830	119.66	3.01	0.734146	2.209780488	11.78549593	9.84915254	0.084	0.020488	0.00172098	0.119512	0.099876
845	133.35	3.33	0.812195	2.704609756	14.42458537	10.8170869	0.095	0.023171	0.00220122	0.152862	0.114633
900	93.51	2.78	0.678049	1.88497561	10.05320325	10.7509392	0.055	0.013415	0.0007378	0.051236	0.054792
915	112.89	3.01	0.734146	2.209780488	11.78549593	10.4398051	0.085	0.020732	0.0017622	0.122375	0.108402
930	96.46	2.9	0.707317	2.051219512	10.9398374	11.3413201	0.06	0.014634	0.00087805	0.060976	0.063213
945	189.67	3.8	0.926829	3.52195122	18.78373984	9.90337947	0.17	0.041463	0.00704878	0.489499	0.258079
1000	211.28	4	0.97561	3.902439024	20.81300813	9.85091259	0.2	0.04878	0.0097561	0.677507	0.320668
1015	301.97	4.58	1.117073	5.116195122	27.28637398	9.0361208	0.329	0.080244	0.02640024	1.83335	0.60713
1030	259.18	4.32	1.053659	4.551804878	24.27629268	9.36657639	0.319	0.077805	0.02481976	1.723594	0.665018
1045	153.27	3.55	0.865854	3.073780488	16.39349593	10.6958282	0.1	0.02439	0.00243902	0.169377	0.110509
1100	179.52	3.8	0.926829	3.52195122	18.78373984	10.4633132	0.17	0.041463	0.00704878	0.489499	0.272671
1115	250.31	4.29	1.046341	4.488804878	23.94029268	9.56425739	0.272	0.066341	0.01804488	1.253117	0.500626
1130	301.19	4.56	1.112195	5.071609756	27.04858537	8.98057219	0.326	0.079512	0.02592098	1.800068	0.597652
1145	451.04	5.2	1.268293	6.595121951	35.17398374	7.79841782	0.566	0.138049	0.07813561	5.426084	1.203016
1200	346.45	4.75	1.158537	5.50304878	29.3495935	8.4715236	0.407	0.099268	0.0404022	2.805708	0.809845
1215	868.08	6.31	1.539024	9.711243902	51.79330081	5.96642024	1.26	0.307317	0.38721951	26.89024	3.097669

1245	601.12	5.68	1.385366	7.868878049	41.96734959	6.98152608	0.81	0.197561	0.16002439	11.1128	1.848683
1300	493.51	5.35	1.304878	6.981097561	37.23252033	7.54443078	0.644	0.157073	0.10115512	7.024661	1.423408
1315	507.65	5.45	1.329268	7.244512195	38.63739837	7.6110309	0.6	0.146341	0.08780488	6.097561	1.201135
1330	450.38	5.2	1.268293	6.595121951	35.17398374	7.80984585	0.57	0.139024	0.0792439	5.503049	1.221868
1345	521.13	5.4	1.317073	7.112195122	37.93170732	7.27874183	0.67	0.163415	0.1094878	7.60332	1.459006
1400	459.23	5.25	1.280488	6.722560976	35.85365854	7.80734241	0.635	0.154878	0.09834756	6.829692	1.487205
1415	646.89	5.73	1.397561	8.00802439	42.70946341	6.60227603	0.88	0.214634	0.18887805	13.11653	2.027629
1430	614.41	5.7	1.390244	7.924390244	42.26341463	6.87869902	0.835	0.203659	0.17005488	11.80937	1.922066
1445	511.93	5.45	1.329268	7.244512195	38.63739837	7.54739874	0.66	0.160976	0.1062439	7.378049	1.441222
1500	428.52	5.1	1.243902	6.343902439	33.83414634	7.89558162	0.534	0.130244	0.06955024	4.829878	1.127107
1515	240	4.15	1.012195	4.200609756	22.40325203	9.33468835	0.246	0.06	0.01476	1.025	0.427083
1530	309.58	4.6	1.121951	5.16097561	27.52520325	8.89114389	0.331	0.080732	0.0267222	1.855708	0.599428
1545	373.87	4.85	1.182927	5.737195122	30.59837398	8.1842282	0.452	0.110244	0.04983024	3.460434	0.925571
1600	171.62	3.7	0.902439	3.33902439	17.80813008	10.3764888	0.154	0.037561	0.00578439	0.401694	0.23406
1615	170.67	3.7	0.902439	3.33902439	17.80813008	10.4342474	0.145	0.035366	0.00512805	0.356114	0.208657
1630	191.56	3.89	0.94878	3.690756098	19.68403252	10.2756486	0.188	0.045854	0.00862049	0.598645	0.31251
1645	257.47	4.31	1.05122	4.530756098	24.16403252	9.38518372	0.27	0.065854	0.01778049	1.234756	0.479573
1700	246.55	4.29	1.046341	4.488804878	23.94029268	9.71011668	0.267	0.065122	0.01738756	1.20747	0.489746
1715	194.53	3.9	0.95122	3.709756098	19.78536585	10.1708558	0.188	0.045854	0.00862049	0.598645	0.307739
1730	177.38	3.7	0.902439	3.33902439	17.80813008	10.0395366	0.149	0.036341	0.00541488	0.376033	0.211993
1745	159.82	3.61	0.880488	3.178560976	16.9523252	10.6071363	0.11	0.026829	0.00295122	0.204946	0.128235
1800	120.63	3.15	0.768293	2.420121951	12.90731707	10.699923	0.081	0.019756	0.00160024	0.111128	0.092123
1815	69.51	2.3	0.560976	1.290243902	6.881300813	9.89972783	0.054	0.013171	0.00071122	0.04939	0.071055
1830	40.52	1.9	0.463415	0.880487805	4.695934959	11.5891781	0.021	0.005122	0.00010756	0.00747	0.018434
1845	8.6	0.3	0.073171	0.02195122	0.117073171	1.36131594	0.005	0.00122	6.0976E-06	0.000423	0.004924
1900	0	0	0	0	0	0	0	0	0	0	0